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SOME EXPERIENCE WITH SIDE CONTROLLERS

By S. A. Sjoberg

Langley Aeronautical Laboratory

INTRODUCTION

With the X-15 airplane, the pilot will be subjected to longitudinal accelerations as large as about 5g. There is some question as to whether or not a pilot will be able to control the airplane by using a conventional control stick when he is subjected to accelerations of this magnitude. In order to alleviate the acceleration effects, it is planned with the X-15 airplane to use a side controller and to restrain the pilot's arm through use of an armrest.

Some problems are anticipated with the use of a side controller. Aside from the different location, which may affect the pilot's controlling ability, the motions of a side controller will be smaller by a factor of about 3 to 6 depending upon the particular design, and thus the mechanical advantage between the stick and the control surface must be reduced. This may cause the side controller to be overly sensitive. Further, the pilot's force capabilities are smaller and this, together with the reduced mechanical advantage, will make the friction forces more important.

Flight tests and ground-simulator studies have been made to study some of these problems and it is the purpose of this paper to present some of the results obtained.

F9F-2

Some flight experience with a side controller has been obtained with one installed in an F9F-2 airplane. Figure 1 is a photograph of this controller. Although this controller is different from that currently proposed for the X-15, the flight experience with it has indicated the feasibility of flying with a side controller and has furnished some information on satisfactory deflection and force gradients.

The F9F-2 controller is simply a short stick (about 4 inches long) which is pivoted at the bottom for both longitudinal and lateral motions. It has been used with electric-power control systems, and the control-valve friction normally present in hydraulic power controls is thus eliminated. The forces required to move this stick are light, with about 4 pounds of force being required for full stick deflection. Since the forces are light, the pilots prefer to grip the stick with their fingers and to use finger and wrist motions in moving it rather than arm motions. The friction forces with this controller are between 1/2 and 1 pound and the pilots considered this amount of friction to be within the acceptable range.

Figure 2 shows the stick forces and motions required in steady pull-up maneuvers with the F9F-2 airplane when using the side controller. The upper curve shows the variation of the stick force per g with Mach number, and the lower curve shows the stick motion per g. At Mach numbers between 0.6 and 0.8, where most of the maneuvering was done, the force per g is about $1\frac{1}{2}$ pounds. Most of the pilots were of the opinion that the forces were of about the right magnitude. However, some of the pilots thought they would prefer heavier forces.

The magnitudes of stick motion per g (which at a Mach number of 0.6 is about 0.35 inch) were satisfactory in the pilots' opinions. The stick motions per g are larger with the F9F-2 side controller than those estimated for the X-15 at some flight conditions. At a Mach number of 4.0 and a dynamic pressure of 2,000 pounds per square foot with the X-15, the stick motion per g has been estimated to be about 0.10 inch.

Figure 3 shows the variation of steady rolling velocity with lateral stick motion and lateral stick force with the side controller in the F9F-2 airplane. In this case, full stick throw of almost 2 inches requires a force of about 4 pounds and produces a rolling velocity of about 150 deg/sec. The pilots considered the lateral control characteristics documented here to be satisfactory.

Fourteen pilots have flown the F9F-2 airplane by using the side-located controller. Included in the flying were take-offs, landings, stall approaches, aerobatics, air-to-air tracking, and rough-air flying. All the pilots liked flying with the side controller. They were able to become accustomed to it quickly and found it comfortable and natural to use.

PROPOSED X-15 SIDE CONTROLLER

The design of the side controller for the X-15 has not been definitely established as yet. However, a design now contemplated is shown in figure 4. The solid outline of the controller grip indicates the neutral position and the dashed outlines show the maximum deflections. The controller motion which produces pitching is a pivoting motion about the pilot's wrist. An upward grip motion is required for a pull-up and a downward motion for a push-down. The axis for roll control motions is at the bottom of the grip and it remains perpendicular to the grip when longitudinal control is applied.

The X-15 controller will be used with a hydraulic power control. This introduces some additional factors which may affect the pilot's ability to control. Some of these factors are being studied by using a ground simulator.

SIMULATOR

Figure 5 is a photograph of the simulator. This simulator duplicates the short-period pitching motion of an aiprlane and the pilot controls the simulator motion through a hydraulic-power control system. The side controller here has motions similar to the one proposed for the X-15.

One of the X-15 flight conditions used in the simulator tests was a Mach number of 4.0 and a dynamic pressure of 2,000 pounds per square foot. For this flight condition the following characteristics were held constant: $\alpha/g = 1.3^{\circ}$; $\dot{\theta}/g = 0.5$ deg/sec; period, 1.2 seconds; damping ratio, 0.3. The following table lists the control-system characteristics varied in the simulator tests and the effect of the change made.

Variables	Initial value	Changed to -	Effect of change (pilots' opinions)
Valve friction	0	±4.8 lb	Intolerable
Stick friction	±0.5 lb	±3.5 lb	Maximum tolerable
Control sensitivity	d_s/g = 0.07 in. F/g = 2.2 lb	0.30 in. 0.6 lb	Good control characteristics

The variable labelled "valve friction" is actually the stick force required to overcome the valve friction. The "stick friction" is the friction in the control system other than the valve friction.

With these initial values of 0 valve friction, 1/2 pound of stick friction, a stick motion of 0.07 inch per g, and a stick force of 2.2 pounds per g, the pilot rated the control characteristics as fair. He had no real difficulty in controlling and his only objection was that the control motions were too small.

When the valve friction was increased from essentially 0 to 4.8 pounds (while keeping the initial values of stick friction and control sensitivity) the pilot considered the system to be intolerable and almost unflyable because of pilot-induced oscillations. It should be pointed out that this value of valve friction is quite low. If it were present with a conventional control stick a stick force on the order of 1 pound would be required to overcome it.

With the initial values of valve friction and control sensitivity, the maximum tolerable stick friction (or breakout force) was found to be about 3.5 pounds. This is about the same value that has been found previously with the simulator for a conventional center-located stick. This value of a maximum tolerable stick friction of 3.5 pounds is based on considerations of pilot fatigue and precision control.

When the stick motion per g was increased and the stick force per g was simultaneously reduced to the values shown, while keeping the valve and stick frictions at the initial values, the pilot noted an improvement in the control characteristics mainly because of the larger stick motions. The initial stick motion per g of 0.07 inch is close to that estimated for the X-15 at this flight condition.

As noted previously, the pitching velocity per g is only about 0.5 deg/sec at a Mach number of 4.0. It is the pilot's opinion that the small pitching velocity per g makes controlling easier because he is less likely to induce oscillations. This was checked on the simulator by increasing the pitching velocity per g by 4 times (which corresponds to flight at a Mach number of 1.0). The effect of this was to make the simulator considerably more difficult to control.

TV-2 AND F-102

A controller having motions similar to the proposed X-15 side controller also has been installed in a TV-2 airplane. Figure 6 is a photograph of the controller installation in the TV-2. This controller is also being used with hydraulic-power control system. In an effort to reduce the control-valve friction to an acceptable level, vibrators are mounted on the control valves of the hydraulic actuators.

The flight program with this installation is just getting under way and only a few preliminary flight tests have been made. These preliminary tests have emphasized some of the problems. The presence of some valve friction together with some backlash and flexibility has caused the control system to be unsatisfactory on the initial flights. An effort is being made to eliminate these deficiencies. The pilot who has made these two preliminary flights has commented that the motion required for longitudinal control (that is, pivoting about the wrist) is not natural to him and his force capabilities are quite limited. With increased experience this may not be too important.

A side controller has recently been installed in an F-102 airplane by Convair. This controller is being used with hydraulic-power control systems. Little information has been published concerning this controller but apparently it has been well received by the pilots.

CONCLUDING REMARKS

The results obtained with the F9F-2 airplane indicate that the pilots basically have no difficulty in flying an airplane using a side controller. However, control-system friction forces, particularly valve friction, must be greatly reduced from the values which are tolerable with conventional center-located sticks.

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SIDE CONTROLLER IN F9F-2 AIRPLANE

Figure 1

STEADY PULL-UP CHARACTERISTICS WITH SIDE CONTROLLER IN F9F-2 AIRPLANE

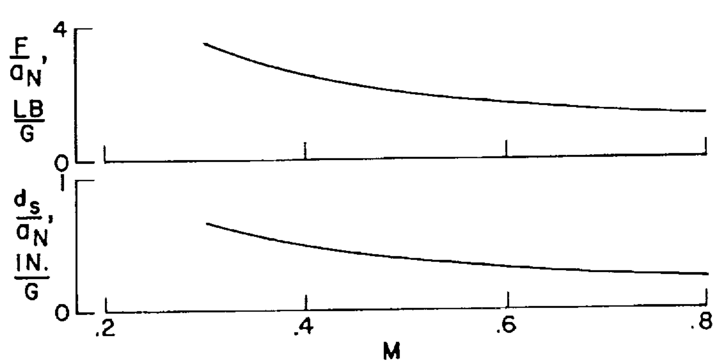

Figure 2

[redacted]

ROLLING CHARACTERISTICS WITH SIDE CONTROLLER IN F9F-2 AIRPLANE

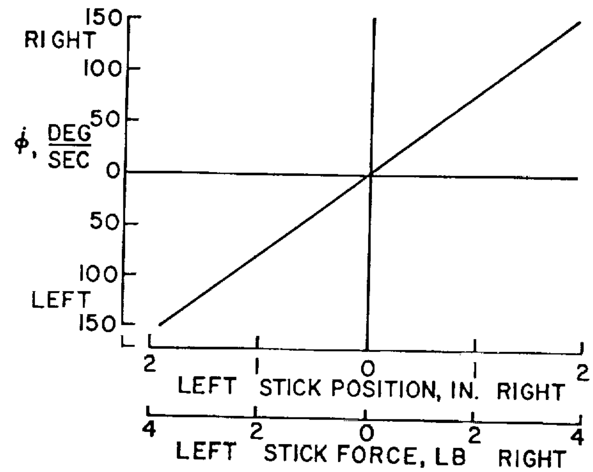

Figure 3

SIDE VIEW OF PROPOSED SIDE CONTROLLER FOR X-15

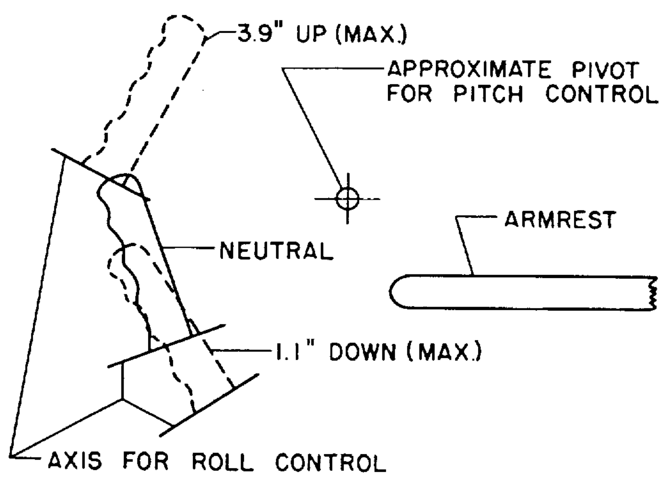

Figure 4

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PITCH SIMULATOR WITH SIDE CONTROLLER

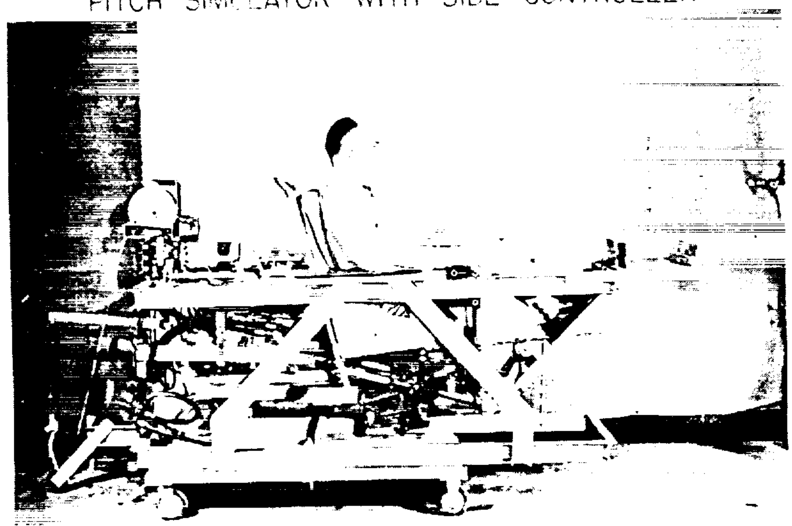

Figure 5

SIDE CONTROLLER IN TV-2 AIRPLANE

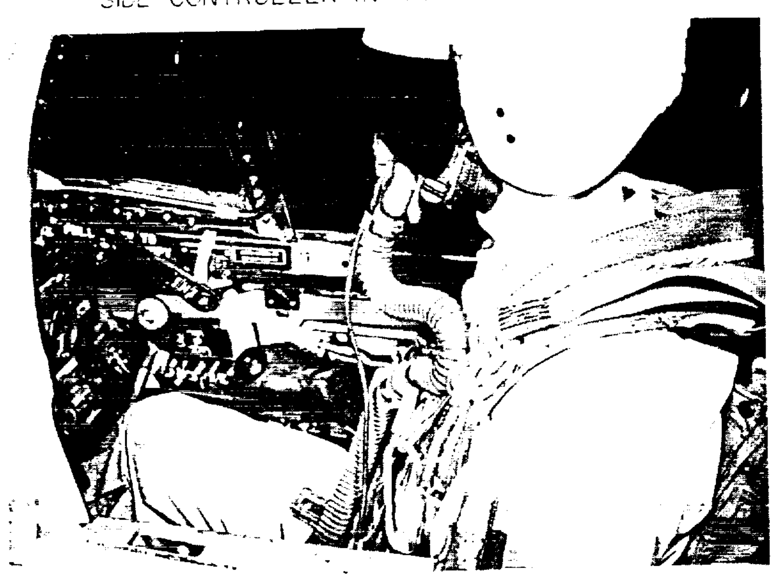

Figure 6

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